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**VIRTUAL FLIGHT TESTING CONCEPTS AND APPLICATIONS**

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**Abstract**

Test and evaluation of modern weapon systems is a complex, costly, and time-consuming process. Weapon System evaluators are presented with many, often times conflicting issues. For example, to demonstrate system performance at the required confidence values often requires that an excessive number of flight tests be performed. Unfortunately, in today's funding constrained environment, this is not practical from a cost standpoint. For this reason, the use of computer simulations in the Test and Evaluation community has emerged as a primary means of verifying over-all weapon system performance. While models and simulations have their roles in performing high numbers of Monte Carlo runs, they usually require a high level of verification and validation to ensure proper representation of the system, threat and test environment. The concept of virtual flight-testing provides an excellent compromise between performing actual flight tests and running traditional digital simulations. Virtual flight-testing utilizes actual flight test data taken on multiple object types, from numerous tests to create new flight test scenarios that were never physically flown. The ability to manipulate the flight test data in both range (space) and time allows existing flight test data (often from multiple tests) to be combined to create a new "virtual" flight test. This process also provides a much higher level of confidence than traditional simulations, since all the data is real. All the signatures of the test vehicles are real, so the threat model validity is no longer an issue. Similarly, all the sensor effects are inherently included in the data, so the sensor model validity is no longer an issue either. Virtual flight-testing is a proven capability, which has evolved and merged out of the data analysis and simulation areas. Signature data, taken at appropriate aspect angles, can be "re-flown" on any three degree-of-freedom trajectory desired. This signature data may come in the form of flight data or static pattern data taken from a range. The only restriction associated with the flight test data, is that only trajectories with

"observed" aspect angles may be flown. In other words, an outbound trajectory with high aspect angles (90-180°) cannot be created from an inbound flight test with low aspect angles (0-90°). As long as this restriction is not violated, any observed flight test target can be re-flown on any desired trajectory. This is an extremely powerful capability, which has been demonstrated on multiple projects for the U.S. Army Space and Missile Defense Command.

**Introduction**

As noted in the abstract, virtual flight testing is a powerful concept that can preserve valuable, limited test resources while simultaneously providing high statistical confidences. The concept is relatively simple: use existing flight test data in an "artificial environment" to create new and distinctly different flight tests which were never actually flown. On the surface this may sound far-fetched or impossible, but the concept has been demonstrated on several different occasions and an example will be shown in this paper. This paper will outline the virtual flight testing concept and provide the basic process used to create new scenarios. It will also highlight the uses, benefits and the limitations associated with virtual flight testing. Lastly, a host of possible scenarios and applications will be identified which might intrigue the reader to learn more about what is being done in this fascinating area which marries flight test data and simulations together.

**Background Of Virtual Flight Testing**

XonTech, Inc. has historically been involved in three main business areas related to missile defense. These three focuses have largely, although not exclusively, focused on radar applications in testing and data analysis, algorithm development and simulations. This unique background made virtual flight testing a natural evolution for XonTech as a company. One of the primary needs of the algorithm developers has always been live data to test the algorithms against. Additionally, one of the primary needs of the simulation designers is to verify the simulation

against live sensor and threat data. Having a wealth of this type of data has made algorithm and simulation testing and verification possible. Unfortunately, even with this extensive database of live flight test data, even XonTech found a lack of relevant live data to test some algorithms and simulation functionality. A very good example of this is in the area of kinetic kill intercepts of Theater Ballistic Missiles (TBMs). There is not much (if any) relevant flight test data to test Ballistic Missile kill assessment algorithms against. Additionally, even when a test set of relevant data did exist, the analysts would typically want more. This has especially been true where algorithm verification is concerned because many of the algorithms have extremely stressing statistical performance requirements, which are being verified. To meet these requirements might require thousands of data sets, which obviously are not available.

The solution to this problem has been to artificially manipulate the test data into "new" scenarios. In the case of a kinetic intercept of a TBM, for example, it will be shown how test data from numerous sources can be combined to create a virtual intercept. Additionally, the characteristics of the intercept event can be modified to meet whatever conditions the user desires. For example, the specific numbers of pieces of debris can be specified. The intercept time can be moved forward or backward in time. The intercept point can be changed. The debris velocity can be changed. The width of the debris cloud as a function of time can be changed. A surviving warhead or other large objects can be embedded in the debris. All of these important parameters can be modified or manipulated to assess their impact on the kill assessment algorithm's performance.

#### Why Do Virtual Flight Testing?

Conventional flight testing of Ballistic Missile Defense systems has become extremely complex and costly. Numerous programs have had the number of planned flight tests drop significantly due to cost. This was seen on the THAAD Program, which was originally planned for twenty flight tests at the time it went through the Milestone I Defense Acquisition Board. The National Missile Defense Program has already limited the number of flight tests to less than ten, due to the costs and complexities. In an effort to save time and dollars, virtual flight testing may

be viewed as a reasonable compromise between conventional flight testing and traditional digital simulation.

One of the problems with traditional simulations is verification, validation and accreditation of the simulation. This must be examined on several levels. First, the model must adequately represent the sensor or system it is modeling in enough fidelity to assess the predicted performance. Secondly, the targets and threat must be modeled in sufficient detail to ensure that the model is properly considering all of the target characteristics and attributes which might affect performance. Lastly, the environments must be modeled in enough detail to represent "the real world" effects that will be seen in a tactical environment.

Virtual Flight Testing does not have these three concerns, because the data is real. An actual sensor is used to collect the data, so all the relevant sensor effects (for that particular sensor and sensors which are similar) are inherently included in the data. Likewise, the targets are real, so there are no verification issues associated with those systems. In many cases, the threat systems can be used to represent other threats that are very similar. In these cases, the term "surrogate" will be used. The only thing that must be verified when using "surrogate" objects is that the threat data is a reasonable surrogate for the desired system. Lastly, the environments are inherently provided in the data. The environments are not easy to control or manipulate, however. From a data standpoint, the user is pretty much limited to the conditions that existed on the day of the flight test. From a signal to noise standpoint, however, noise can always be added to represent a degraded environment. This process cannot be performed in the other direction, however. In other words, there is little that can be done to improve individual data which was taken under poor conditions (this assumes that normal processing, such as integration, has been performed already to make the data as "clean" as possible).

Virtual Flight Testing can be used as both an enhancement to traditional simulations, as well as a verification tool. The virtual flight test data can be put in identical form as the simulated data to perform side by side comparisons for verification. This is a powerful approach, challenging the verification team to identify the "live" from the simulated data set.

## Process

The virtual flight testing process starts with a large database of live flight test data, as one might imagine. In general, the characteristics of the data collection sensor are well understood. For example, the sensitivity, noise levels, scan and beamshape losses and pulse compression gain are generally well characterized. This allows the data to be manipulated with these factors being fully compensated for. An example would be if data were taken with a phased array radar on an object at a low scan angle (with associated scan losses), this same data could be made to represent a higher scan angle by adding the appropriate losses in the form of added noise. Since the loss as a function of scan angle is known, this can be done very easily. Another example is that the pulse compression effects can be "taken out" by performing an inverse fast fourier transform (IFFT). This will bring the data back to its original In-phase and Quadrature (I & Q) form, which is commonly used in simulations. This technique has also been demonstrated on an actual waveform generator program, which used the "decompressed" I & Q data to generate a real-time, Pseudo-Random Noise (PRN) coded waveform.

Next, an alignment and compensation of the signature data must be performed. The process uses the metric trajectory data to properly align and phase compensate the signature data. This essentially puts the signature at the desired location and time on the trajectory and gives it the correct phase. This is especially important if the data is to be taken back to its I & Q format as referenced earlier.

A data gap filling process may be required next, if all the data is not at the desired sampling rate. This can be performed to gain a factor of two (or so) in data rate, without corrupting the results. This process is basically an interpolation process. For example, if the data is taken at 1,000 Hz (pulses per second), but a 2,000 Hz rate is desired, every second pulse can be generated by interpolating between the surrounding existing pulses. This will fill in the data to the desired data rate. A similar process can be done to filter the data. If a 250 Hz data rate is desired in the example above, only every fourth pulse would be used. This will "thin" the data to the desired data rate.

We often wish to isolate the target signature from the surrounding "noise gates." This is a simple process that involves removing all the range gates, except those of interest, typically containing the target or other objects of interest. At this point, a new signature file is created, containing only the objects of interest with their inherent motion about their center of gravity. This aspect is important, because the object can now be flown on "new" three DOF trajectories, so long as the viewing geometry constraints are not violated.

For combined simulated and virtual flight testing, the same process is used to isolate the target signatures. In addition to adding new trajectories, simulated objects (signatures and trajectories) can now be superimposed into the scene. This gives us the capability to add any simulated objects we desire to the virtual flight test. This is extremely important when we wish to characterize performance against unknown, postulated or follow-on threat systems, which we have no data on.

The process described above offers many opportunities to perform a variety of testing applications. We can test algorithms against live data and vary the signal to noise ratios (SNRs). Fortunately, most of the data is collected at high SNR and noise can be added to replicate the effects of lower sensitivities, as would be experienced at longer ranges or under heavier loading scenarios. Similarly, most of the data is collected at high data rates and the user can fill in or thin the data to replicate different data rates as desired. This is also a critical algorithm test parameter, used to establish how much data is required for the algorithm to converge upon a solution. Different geometries can be generated (assuming that the range of aspect angles is available in the data). Loading excursions can be performed by merely replicating trajectories (again assuming that no geometry constraints are violated).

## Example

Figures 1, 2 and 3 give an example of a virtual flight test. The test scenario is a Theater Missile Defense intercept with a kinetic kill interceptor. Due to the extreme lack of relevant flight test data of this type, this is a natural application of virtual flight testing. There are several "surrogate" objects used in this test, again due to the lack of real TMD kinetic kill intercepts.

Some examples of the surrogates are that a Chinese Naval RV was used to represent a surviving separated warhead. The RV has suitable size, mass and signature to represent the desired warhead in this scenario. Various strategic and domestic fragments and closely spaced objects were used to represent small and large post intercept debris. Again, the objects have the correct sizes and signatures to represent the desired pieces of debris. Figure 1 shows the isolated signatures with their inherent motion about their centers of gravity. These plots show range along the abscissa and time along the ordinate. The colors represent the RCS intensity, according to the scale shown. Notice that the RV can be seen to tumble in this range, time intensity plot. The signature of the RV can also be seen to increase significantly when the aspect angle approaches broadside (when the width of the signature is at its narrowest). As an example of the flexibility, if a doubling of the tumble rate were desired for this signature, the time scale would simply be halved.

Figure 2 shows the virtual intercept. The target is range aligned at 0 meters. The interceptor can barely be seen to enter the range window at 101.7 seconds. The intercept event is clearly visible at 102 seconds, with the corresponding debris patterns from both the target and the interceptor. The resulting target debris pattern has several larger objects embedded in it, including a surviving RV. This can be further seen in the "Zoom" of Figure 3.

This virtual flight test was specifically designed to test algorithms for kill assessment, against the stressing case involving an unsuccessful intercept event. Several other large objects are also embedded, including the rocket nozzle and a couple of large tank segments.

The resulting debris patterns can easily be modified to represent more or less dense debris clouds, by simply increasing or decreasing the number of objects in each. Likewise, the expansion velocities (how quickly the debris spreads out in range) can be made faster or slower by changing the range or time scales. The impact point can be changed by simply realigning the interceptor and target. Additionally, new objects can be embedded in the debris to represent other types of segments or associated hardware.

As an upgrade to this capability, XonTech is currently integrating the U.S. Army's Kinetic Impact Debris Distribution (KIDD) model for virtual flight testing. KIDD will give the "approved" debris distributions and associated velocities for a variety of warhead types and intercept conditions. This will allow parametrics to be performed over various lethality conditions. The virtual flight tester will then create the resulting environments with the applicable real data to fit the debris density, expansion velocity and lethality conditions specified.

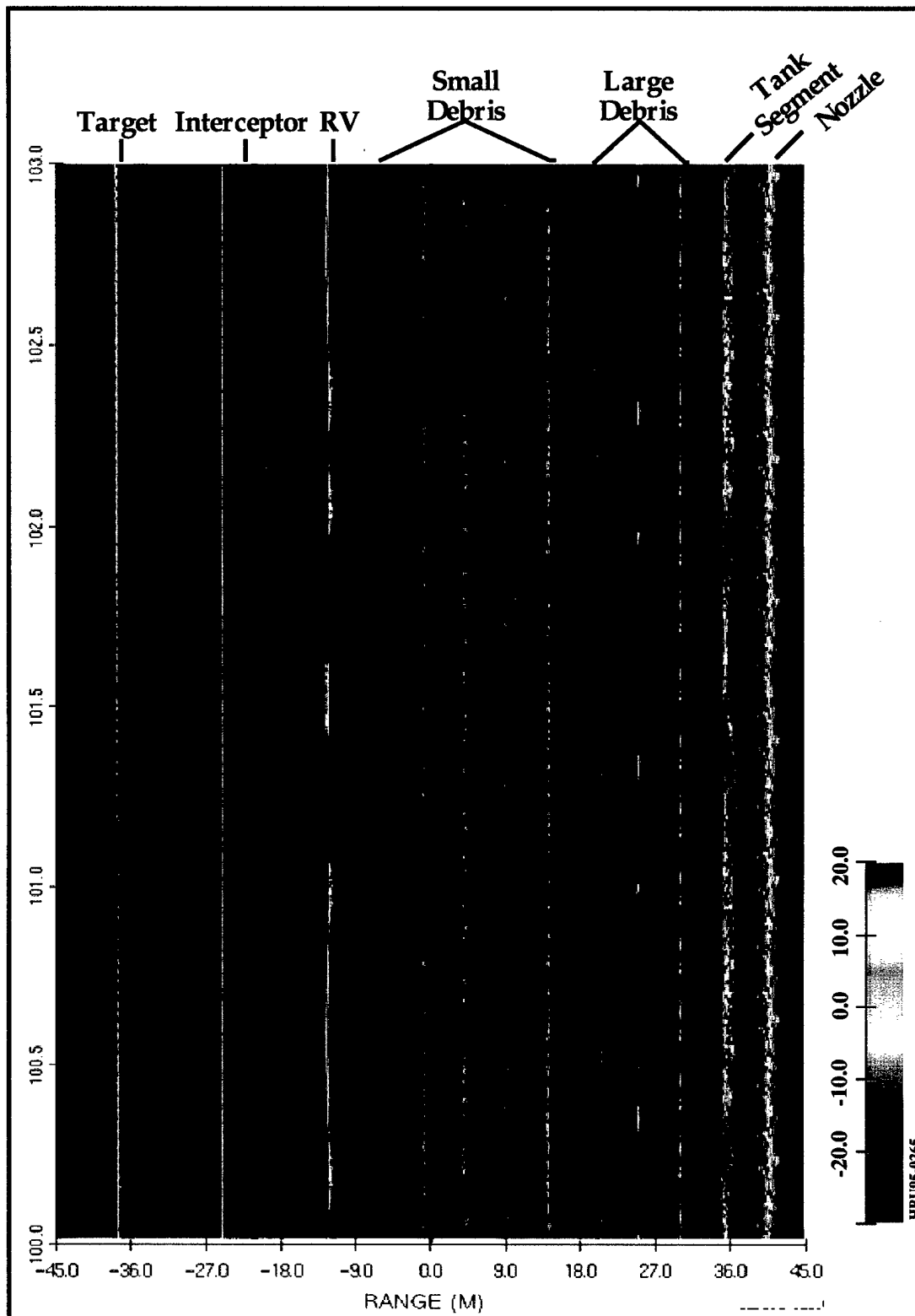


Figure 1. Range-Time Intensity of Objects Used for Virtual Intercept

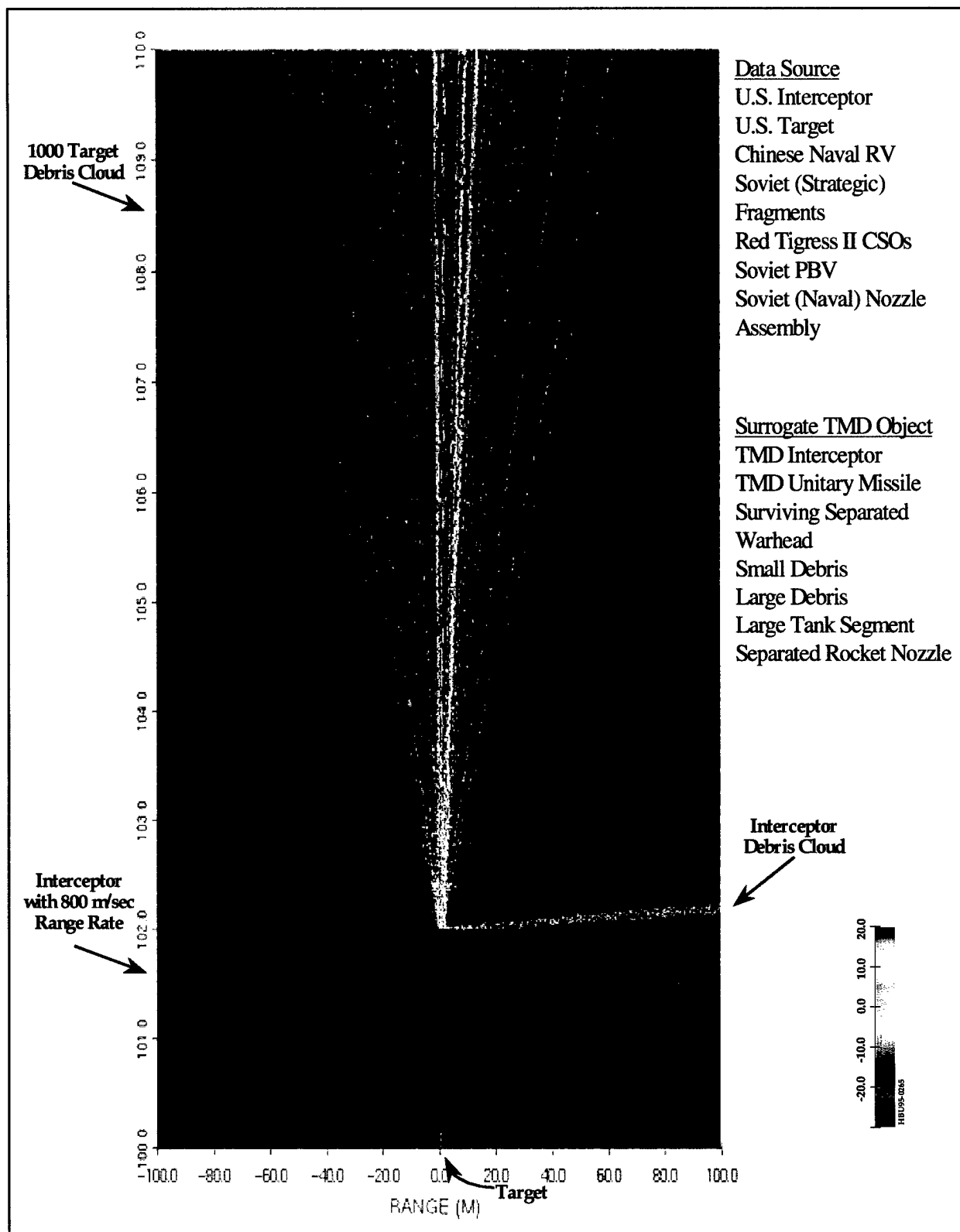


Figure 2. Virtual Flight Testing Example - Synthetic Hit to Kill TMD Intercept for KA Analysis

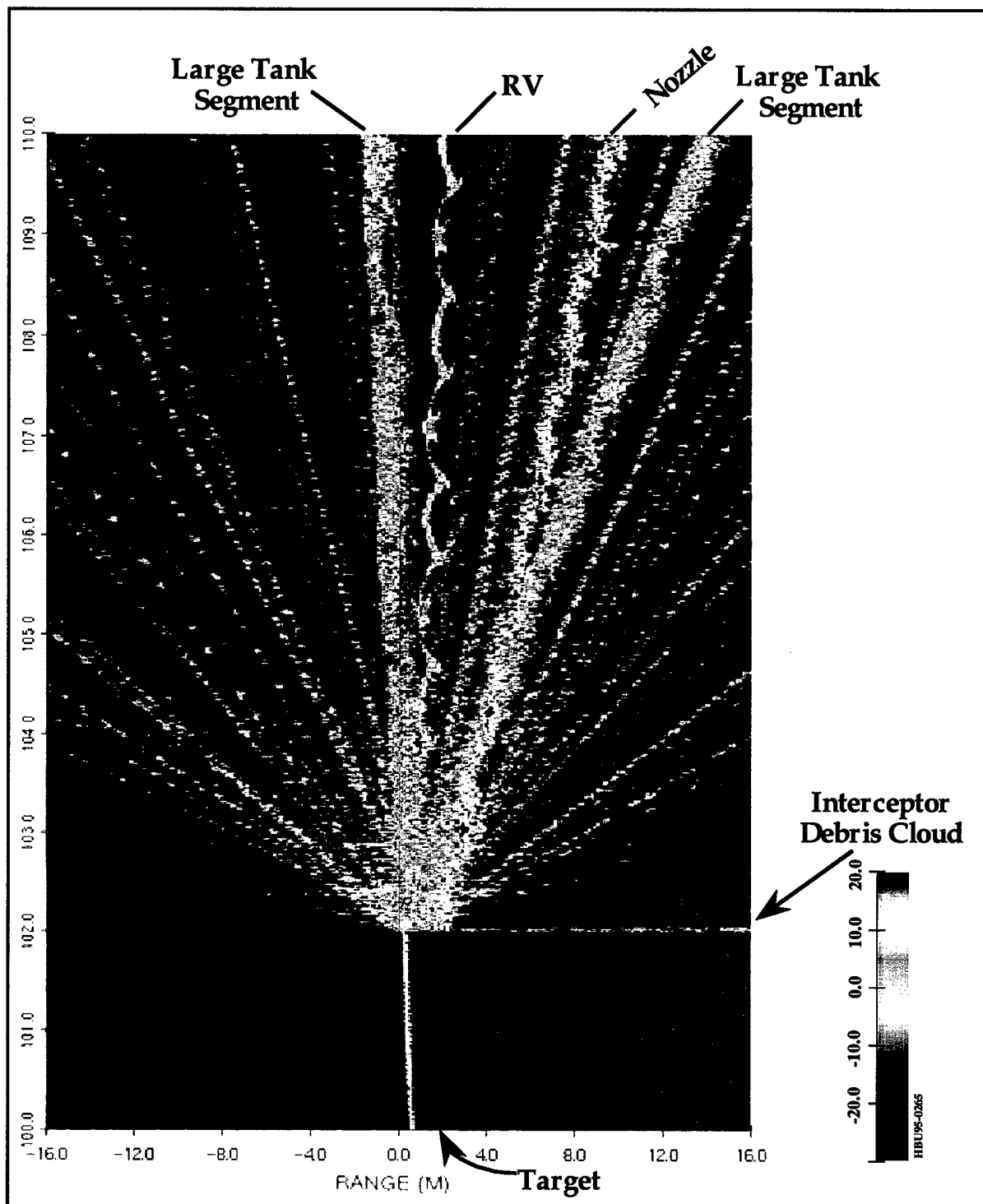


Figure 3. RTI of Virtual TMD Intercept with Surviving RV (Zoom)



### Possibilities

XonTech has a database of over 20,000 different flight test objects, collected on over 1,400 different flight tests. It is this extensive database of re-entry vehicles, associated objects, tanks, guidance and control sections, fragments, shrouds, calibrations spheres, etc. that makes the concept of virtual flight testing possible. Additionally, this data was collected by a variety of different sensors, so virtual flight testing is possible at sensor frequencies ranging from UHF to millimeter wave (MMW).

A host of different applications have been envisioned for virtual flight testing. Some scenarios of interest to the Ballistic Missile Defense community are discussed in the following list. There is no implication of "approved or design-to threat" for any U.S. defense system intended by this shopping list. It is merely a list of possible scenarios and applications which could be "virtual flight tested."

- 1) Create "clouds" of closely spaced objects with fragments, associated objects and deployment hardware to test loading and discrimination.
- 2) Add calibration spheres as "traffic decoys" to test bulk filtering algorithms.
- 3) Embed re-entry vehicles in chaff clouds (live or simulated).
- 4) Combine tumbling replicas with tumbling re-entry vehicles to test discrimination algorithms.
- 5) Create a fragmenting or segmenting booster to test loading, split track and discrimination.
- 6) Simulate an In-flight failure of a Post Boost Vehicle or Tank.
- 7) Generate a discrimination database, using virtual flight testing.

8) Generate a kill assessment database, using KIDD and virtual flight testing.

9) Combine replicas and re-entry vehicles in a common scenario to test advanced discrimination algorithms.

10) Create a catalog of "surrogate objects" suitable for community use and testing of algorithms.

This shopping list provides only a small sample of the possibilities offered by virtual flight testing. It is intended to provoke the reader to come up with his or her own applications and ideas for virtual flight testing.

### Summary

Virtual Flight Testing offers a world of diversity, flexibility and possibility to the test and verification community. The cost savings are tremendous, while overcoming many of the limitations associated with traditional digital simulations. Virtual flight testing allows the tester to use REAL data, on REAL objects, with REAL signatures, taken by REAL sensors in REAL environments. This overcomes many of the verification and validation issues facing the test and simulation community today.

One example of a virtual flight test was presented, showing the benefits and flexibility of the process. A variety of other possible tests and applications were presented to give the reader a better appreciation as to how many different types of scenarios and tests can be performed.

In today's environment of limited budgets and expensive flight tests, virtual flight testing offers a credible, proven approach to reduce cost while maintaining high levels of testing confidence.

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